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An Investor Guide to Hydraulic Fracturing and Water Stress

This update to Ceres' 2014 report, "Hydraulic Fracturing and Water Stress: Water Demand by the Numbers," is designed to help investors analyze key trends in water use and water risk exposure by region and operator. It also provides recommendations for companies to improve their water management and reduce their overall exposure to water sourcing risks.

Water stress is an indication of the level of competition for available water in an area. Extremely high water stress means over 80% of available surface and groundwater is already allocated for municipal, industrial and agricultural uses.

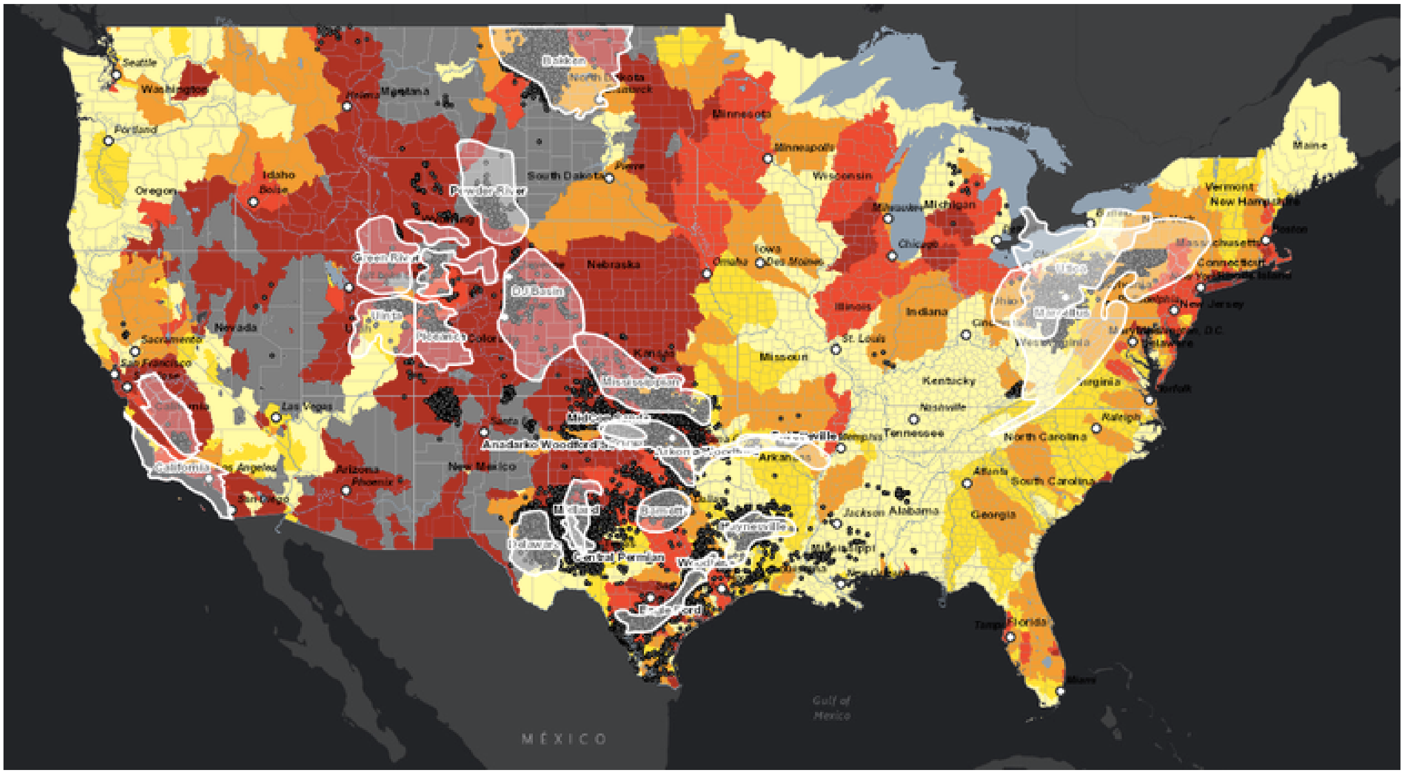
Key Findings

All findings are from January 1, 2011 – January 31, 2016, unless stated otherwise.

- **57% of the 109,665 wells** that were hydraulically fractured in the past five years were located in regions with **high or extremely high water stress,** including basins in **Texas, Colorado, Oklahoma and California**.
- A total of **358.4 billion gallons of water** was used for hydraulic fracturing, equivalent to the annual water needs of 200 mid-sized cities. [1]
- While overall water use peaked in 2014, **average water use per well doubled** from 2.6 million gallons per well in 2011 to 5.3 million gallons per well in 2015, most likely due to longer laterals used to increase contact area with the shale formation.
- The **Eagle Ford** play is of particular concern. Annual water use rose from 5 billion gallons in 2011 to 26 billion in 2014, while average water use (per well) grew from 4 million gallons to over 7 million in 2014. The region is also experiencing high water stress, drought and declining groundwater supplies, along with growing population pressures.
- **Weld County, Colorado** saw the highest number of wells drilled (almost 7000 wells) and the largest amount of water used for fracking (more than 16 billion gallons) of any county in the United States.
- **Local communities are at the front lines of dealing with the impact from water demands for fracking activities.** For example, annual water use for fracking in Weld County, Colorado represents 50 percent of all domestic water use, and in seven of the top 10 counties, annual water use for hydraulic fracturing reached more than 100% of each county's domestic water use
- **Nine of the top 10 companies** analyzed operated **70 percent or more of their wells** in regions with medium or higher water stress.
- The **large volumes of wastewater** produced by hydraulic fracturing that must be managed at the surface and ultimately disposed of in underground deep well injection sites are a significant and growing issue at the local level. This wastewater has been linked to surface and groundwater contamination events, as well as to earthquakes. [2]

Map: Competition for Water in U.S. Shale Energy Development

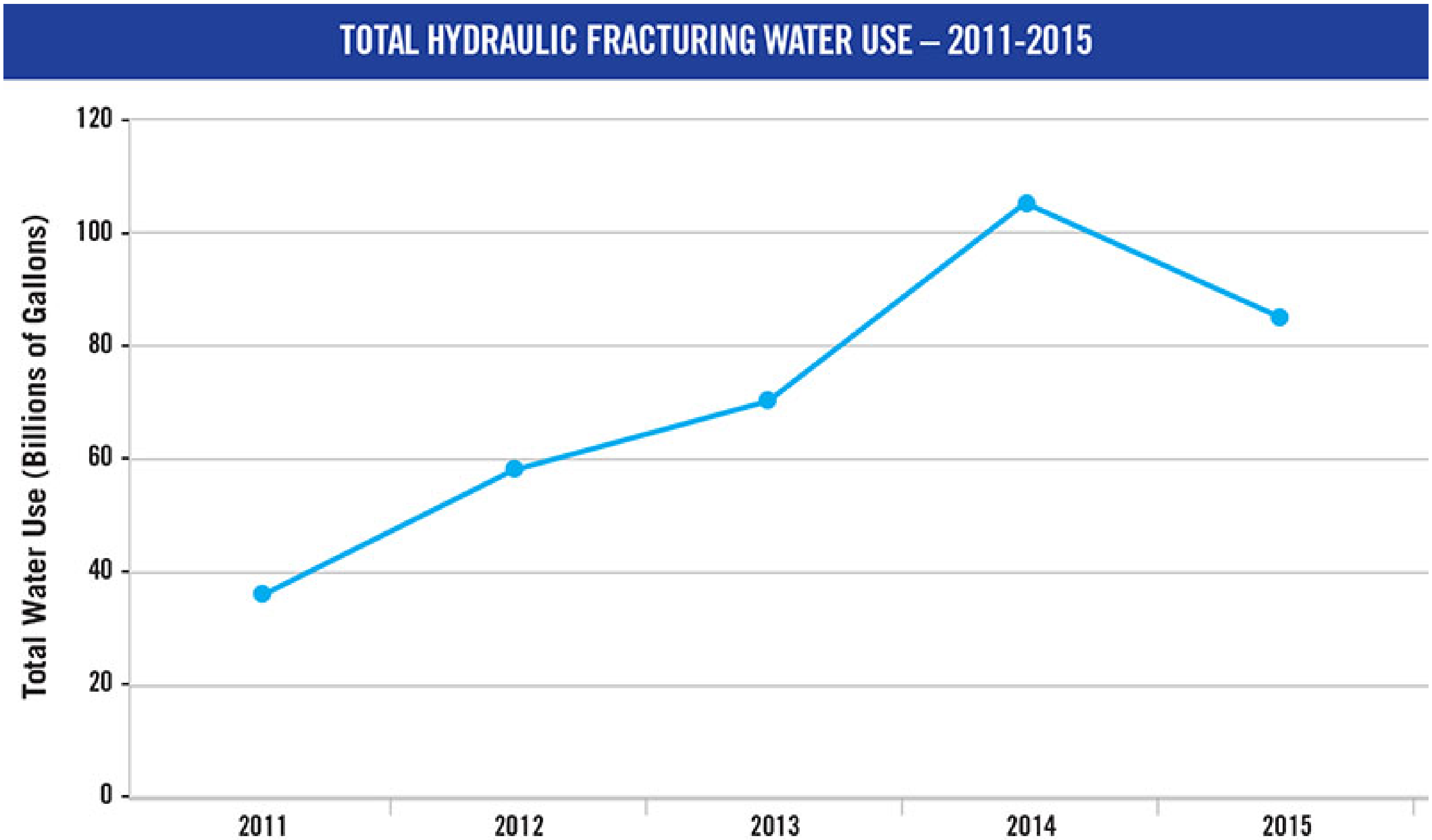
Click to view full sized interactive map, including well locations and related water risk trends



Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org. Data from January 2011-January 2016.

Key Findings: Total Water Use

Fracking's Total Water Use Equal to Annual Water Needs of 200 Mid-Sized Cities



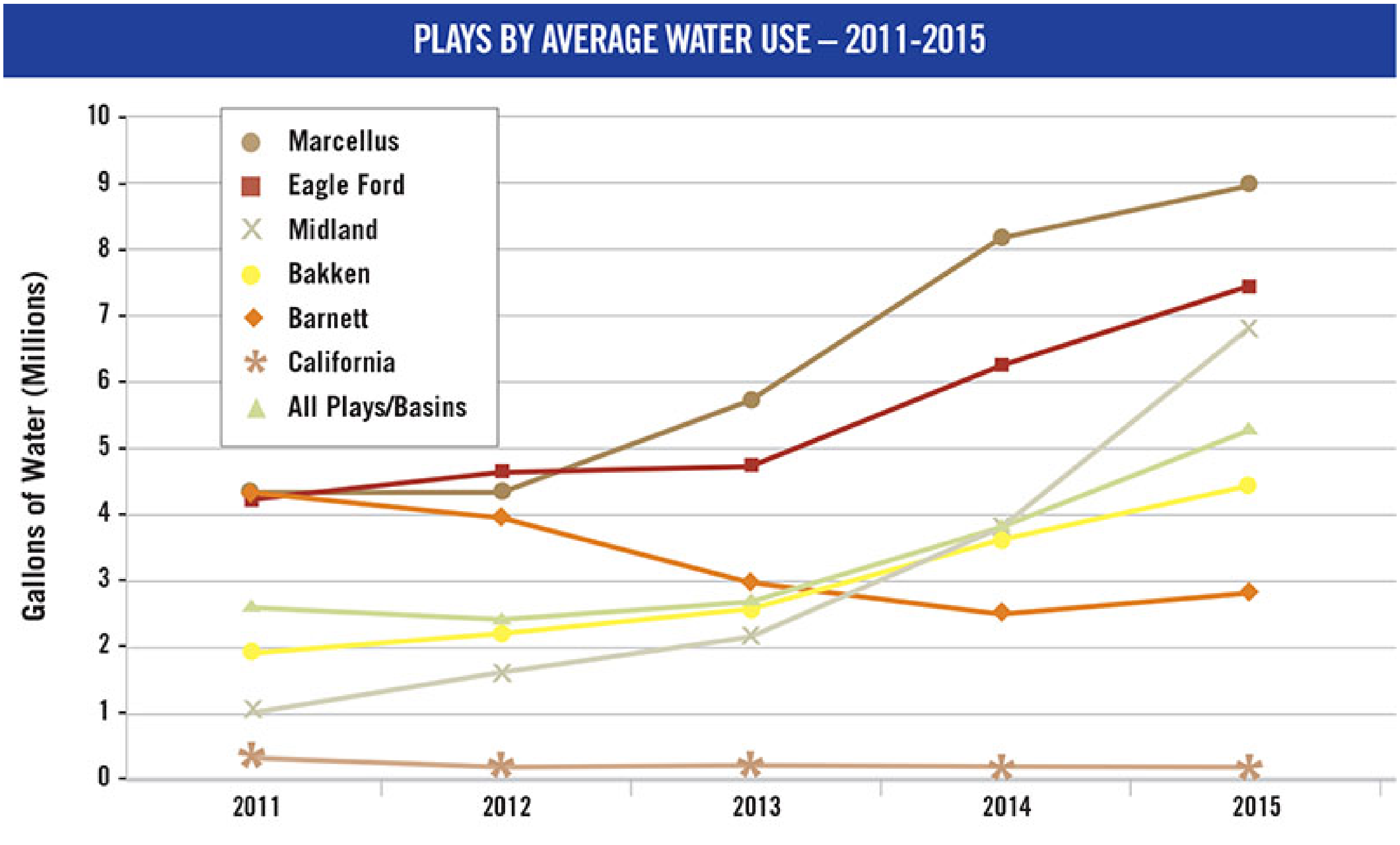
Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org. Data from January 1, 2011-December 31, 2015.

- A total of **358 billion gallons of water was used for hydraulic fracturing** over the 5-year timeframe, equivalent to the annual water needs of 200 mid-sized cities. [3] [4]
- **57% of water used for hydraulic fracturing was in regions of high or extremely high water stress.**
- **Total water use for fracking operations peaked in 2014** with 105 billion gallons of water used for 27,899 wells. While overall water use declined to 85 billion gallons in 2015, water use per well doubled. The overall drop is likely the result of reduced fracking activity due to lower oil and gas prices.

- **48% of fracked wells were in Texas,** with roughly half of these wells in regions of extremely high water stress.
- **82 billion gallons of water (or 25% of water use nationally) was used for fracking operations in the Eagle Ford Play**, 89% of which was taken from regions of high and extremely high water stress. The Eagle Ford (DeWitt, Karnes, Dimmit counties) is a particularly challenging region given increasing population pressures, declining groundwater aquifers and intense local water use.
- **88% of water used in the Midland Play (Permian Region)** – the third highest play by total water use for hydraulic fracturing – was in regions of extremely high water stress. [5]

Key Findings: Average Water Use

Average Water Use Continues to Surge Across Basins and the Industry

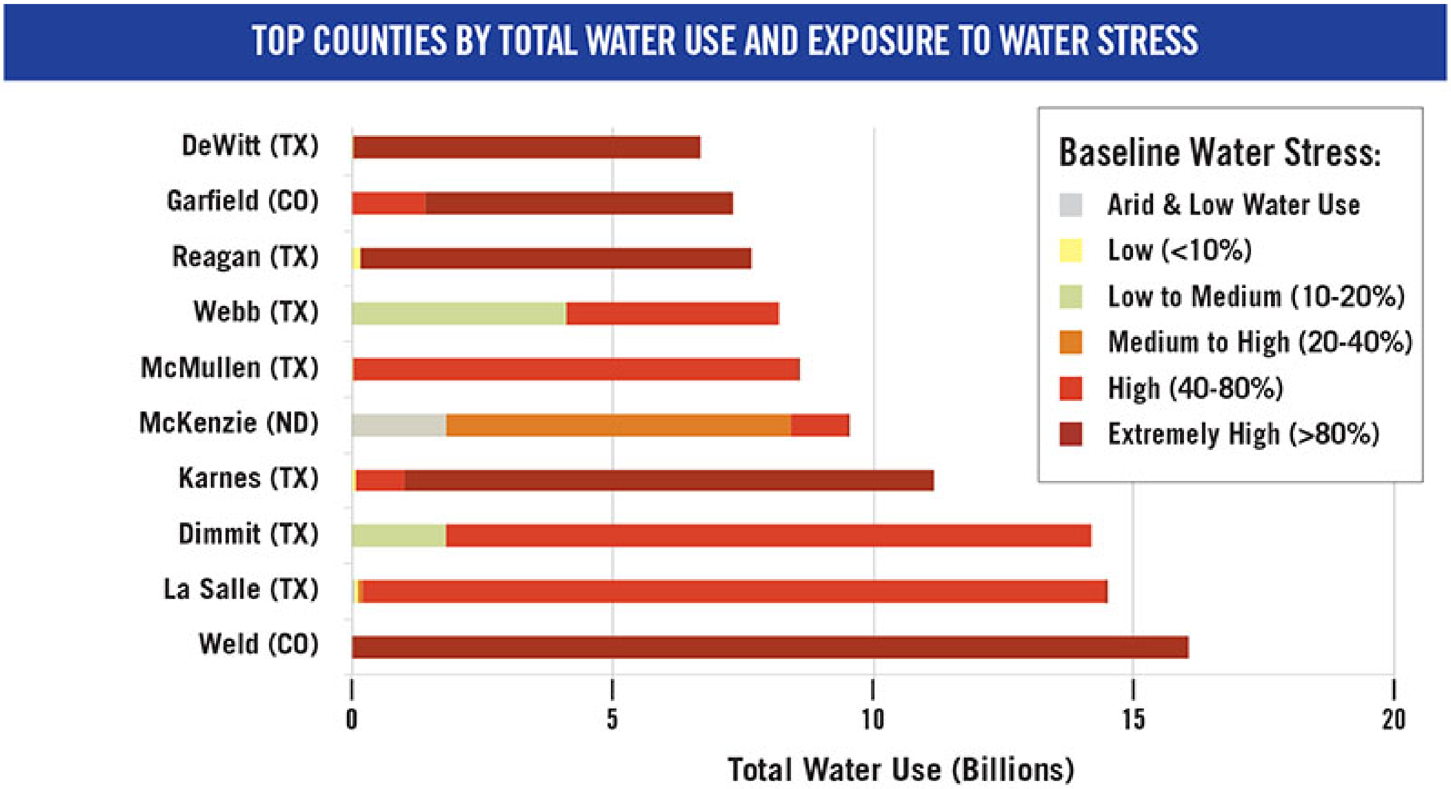


Top five plays by total water use listed with their average water use shown. Addition of California for comparison purposes.
Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org.

- **Average water use increased from 2.6 million gallons per well in 2011 to 5.3 million gallons per well in 2015**, most likely due to longer laterals used to increase contact area with the shale formation. Optimally, water use per unit of energy produced or per meter of lateral pipe laid would be a better indicator of water use efficiency. Overall average water use varies by energy source (oil much lower than gas), the geology of a particular region, operator practices, among potentially many other factors. [6]
- **Average water use was highest in the Marcellus Play** at an average of 9 million gallons per well for 2015, followed by the Eagle Ford and Midland Plays. The Eagle Ford Play was cited at highest risk in the 2014 study, due to drops in groundwater levels, drought and competition for water. Concerns are more heightened now given the ever-increasing trend in water use.

Key Findings by County

Weld County, Colorado, Takes Top Spot in Water Use Nationally



Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org. Data from January 2011-January 2016.

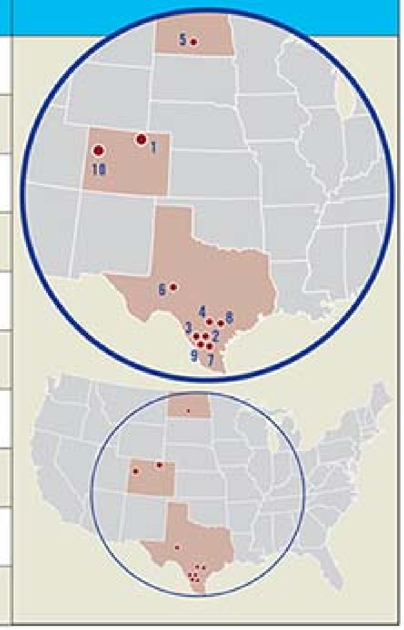
- **6930 wells were hydraulically fractured in Weld County** (CO) using over 16 billion gallons of water, all of which were in areas with extremely high water stress.
- **Six of the top 10 counties by total water use were in the Eagle Ford**, a region of highly concentrated drilling activity, water stress, drought and groundwater concerns.

- In many of the 10 highest water use counties, **water use for fracking was significantly more than domestic water use**, highlighting the potential local burden on communities.
- In seven of the top 10 counties, **annual water use for hydraulic fracturing reached over 100%** of each county's domestic water use.

TOP TEN COUNTIES NATIONALLY BY WATER USE FOR HYDRAULIC FRACTURING AND PROPORTION OF DOMESTIC WATER USE

High Water Use County	Population	Annual Water Use for Hydraulic Fracturing (Billion Gallons)*	Water Use for Domestic Supply (Billion Gallons)**	Hydraulic Fracturing Water Use as Proportion of Domestic Water Use	Number of Wells	Top Two Operators By Water Use
1. Weld (CO)	252,825	4.8	8.9	54%	6,930	Anadarko, Noble
2. La Salle (TX)	6,886	3.4	0.2	1550%	2,215	EP, EOG
3. Dimmit (TX)	9,996	3.0	0.3	990%	2,291	Anadarko, Chesapeake
4. Karnes (TX)	14,824	2.9	0.5	627%	2,281	EOG, Marathon
5. McKenzie (ND)	6,360	2.8	0.2	1487%	2,809	Continental, ExxonMobil
6. Reagan (TX)	3,367	2.5	0.1	1869%	1,481	Laredo, Pioneer
7. McMullen (TX)	707	1.9	0.0	5196%	1,510	EOG, Murphy
8. DeWitt (TX)	20,097	1.8	0.7	251%	1,312	BHP Billiton, ConocoPhillips
9. Webb (TX)	250,304	1.7	5.9	28%	1,584	SM, Lewis
10. Garfield (CO)	56,389	0.6	2.7	22%	2,416	Encana, WPX

County Locations



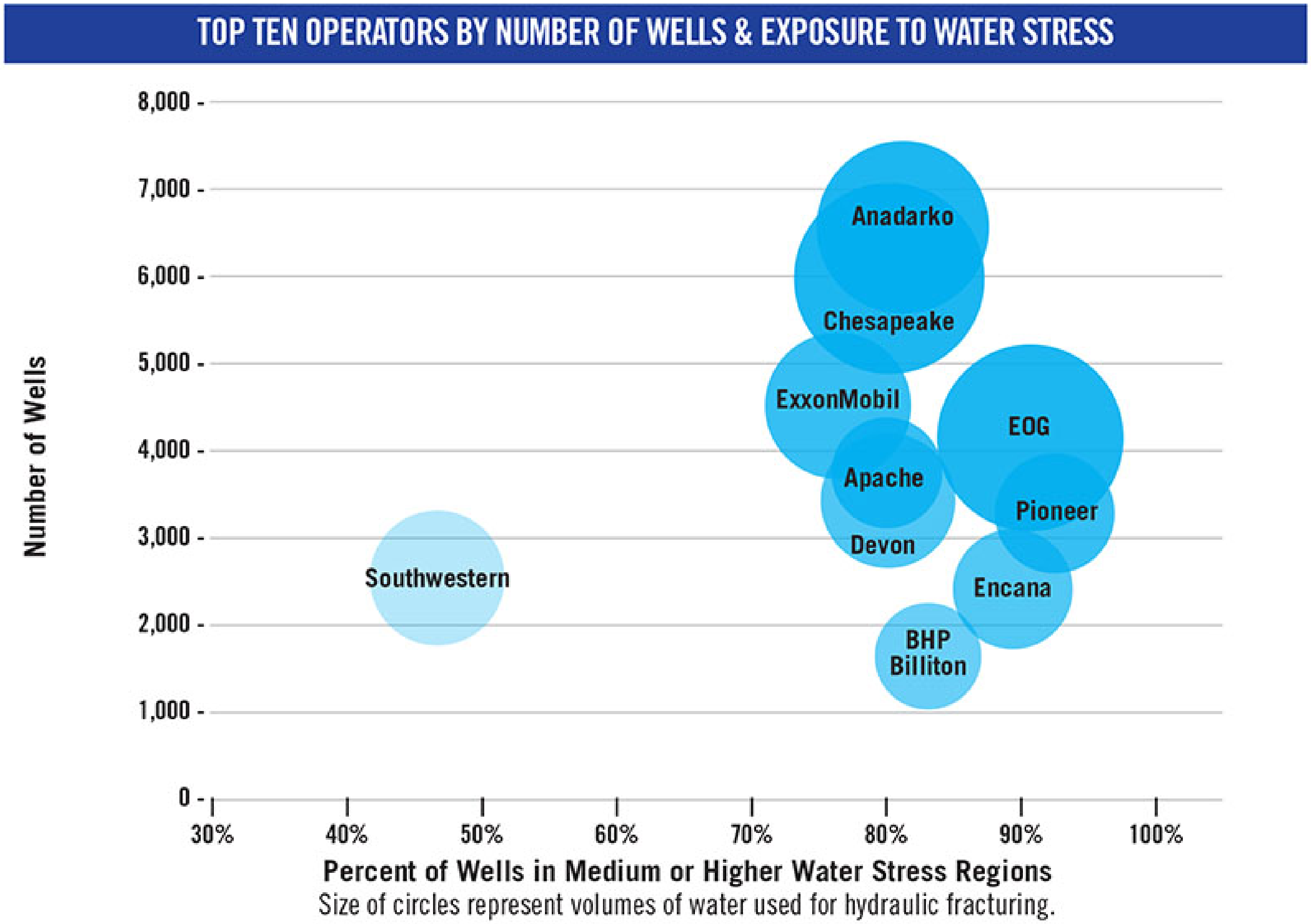
* Hydraulic fracturing annual water use for 2015. Water may have been sourced from outside county and from non-freshwater sources.

** All county-level withdrawal data (i.e. domestic supply) is from USGS 2010 national water survey.

Water use for hydraulic fracturing for 2015 is compared to total domestic use for 2010, the most recent year for which data was available.
Counties with large populations tended to have lower proportions of water use for fracking due to large urban demand.

Key Findings by Company

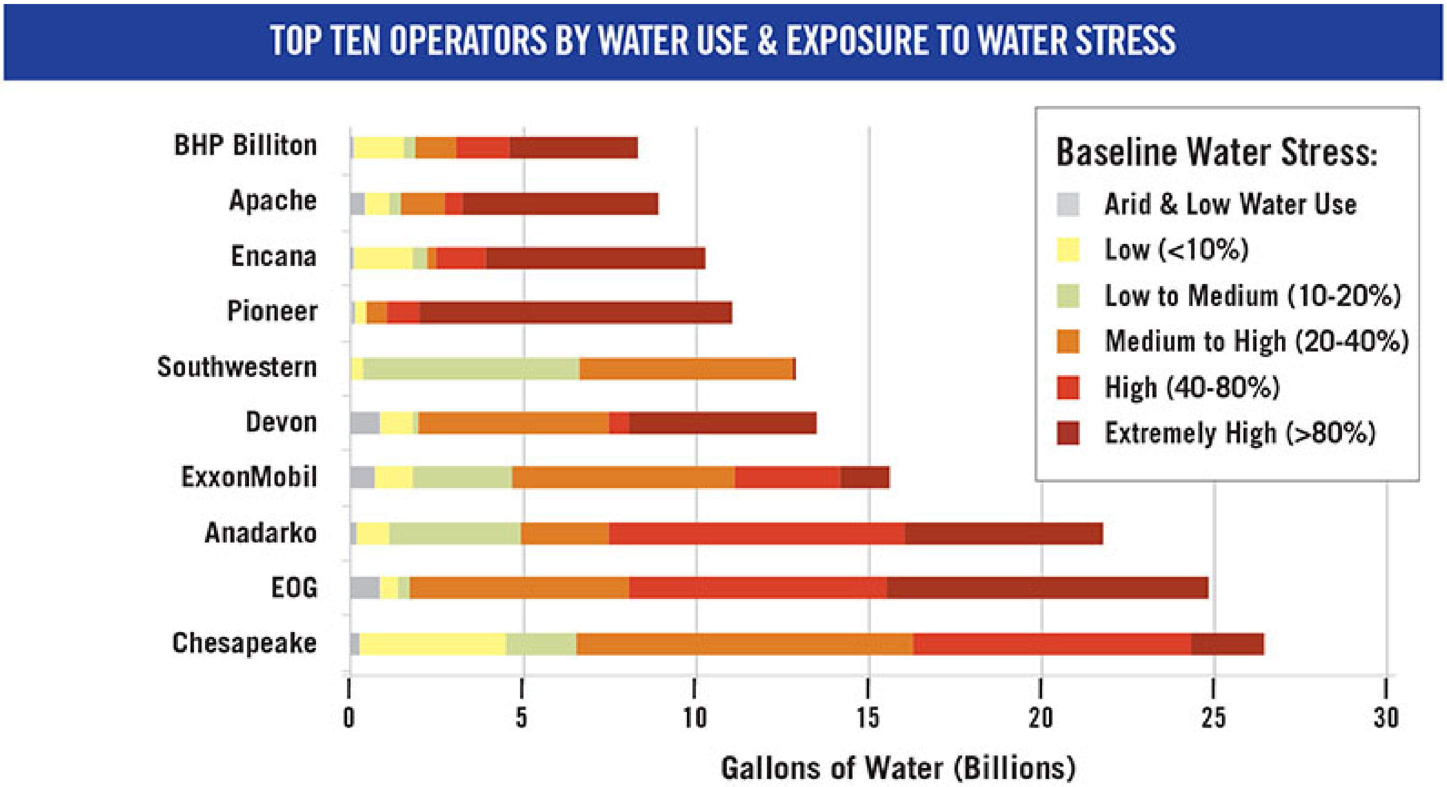
Chesapeake, EOG and Anadarko Have the Largest Reported Water Use



Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org. Data from January 2011-January 2016.

- **Chesapeake used over 26 billion gallons of water,** the most of any operator, followed closely by EOG Resources [EOG] and Anadarko [APC].
- Nine of the top 10 companies by water use operated 70% or more of their wells in regions of medium or higher water stress.
- **91% of EOG's wells were in regions with medium or higher water stress**, while Pioneer Natural Resources [PXD] and Encana [ECA] had greater than 80% of their wells in medium or higher water stress regions.

- EOG Resources [EOG], Southwestern [SWN] and BHP Billiton [BHP] used the most water on average per well, upwards of **5 million gallons each**.
- Of the top 10 operators by total water use, Apache [APA] uses the least amount of water per well, just under 2.4 million gallons.
- Although it is hard to link average water use by operators to operating practices (because variables from well bore design to local geology can explain water use) it is interesting to see that **average water use varies widely by operator in each play**. For example, in the Eagle Ford Play, Chesapeake averaged almost 5 million gallons of water across approximately 1,500 wells, while EOG Resources used on average over 7 million gallons over 1,900 wells in the same play.
- A similar pattern occurs in the Midland Basin with Devon Energy [DVN] and Encana [ECA] averaging **5 million gallons per well** in comparison to Apache's less than 3 million gallon average. Experience in the region and investment in water efficiency measures may help explain these differences.



Source: Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from IHS via FracFocus.org. Data from January 2011-January 2016.

For a more detailed analysis of operator water use trends by play, click on the chart below to expand.

Operator Exposure To Water Stress & Water Use Metrics By Play

Top ten operators/plays/basins by total water use

Red quadrant show significant operational (100+ wells) exposure to water stress (majority of wells in medium or higher water stress). *Market cap as of 09/01/16

Increasing water volumes by play and by company

— PLAY — Operator Ticker Mkt Cap (millions)*	EAGLE FORD Total Water Use (G) Average Water/Well # of Wells	MARCELLUS Total Water Use (G) Average Water/Well # of Wells	MIDLAND Total Water Use (G) Average Water/Well # of Wells	BAKKEN Total Water Use (G) Average Water/Well # of Wells	BARNETT Total Water Use (G) Average Water/Well # of Wells	DJ BASIN Total Water Use (G) Average Water/Well # of Wells	HAYNESVILLE Total Water Use (G) Average Water/Well # of Wells	DELAWARE Total Water Use (G) Average Water/Well # of Wells	ANADARKO WOODFORD/SCOOP Total Water Use (G) Average Water/Well # of Wells	FAYETTEVILLE Total Water Use (G) Average Water/Well # of Wells	ALL OTHER PLAYS Total Water Use (G) Average Water/Well # of Wells	TOTAL VOLUME Total Water Use (G) Average Water/Well # of Wells
Chesapeake Energy Corp.	7,810,215,164	4,419,223,442	66,025,806	12,871,572	2,336,568,771	53,943,010	2,654,722,751	273,020,498	97,112,358	182,939,072	8,514,131,029	26,420,773,473
CHK	4,936,925	5,694,876	1,048,029	2,145,262	3,862,097	2,157,720	5,912,523	2,084,126	2,697,566	3,976,936	3,706,631	4,391,751
$4,740	1,582	776	63	6	605	25	449	131	36	46	2,297	6,016
EOG Resources Inc.	13,974,583,863	285,199,653	1,711,300,825	1,722,398,313	3,602,208,231	443,081,352	707,308,219	1,289,106,291	111,269,506		1,033,181,578	24,879,637,831
EOG	7,233,221	3,034,039	9,300,548	4,693,183	4,745,992	5,152,109	7,858,980	6,679,307	4,279,596		2,295,959	5,950,643
$47,680	1,932	94	184	367	759	86	90	193	26		450	4,181
Anadarko Petroleum Corp.	9,855,890,379	1,205,568,811	1,344,868			5,748,341,704	2,631,540,158	1,379,264,580			931,352,285	21,753,302,785
APC	7,338,712	3,864,003	112,072			2,541,265	8,830,672	4,449,241			451,237	3,295,456
$27,250	1,343	312	12			2,262	298	310			2,064	6,601
Exxon Mobil Corp.	211,162,431	1,371,592,994	1,122,703,179	1,942,484,423	2079215011		1,553,009,159	140,168,065	2,633,525,286	2,752,391,650	2,007,852,093	15,814,104,291
XOM	3,640,732	6,234,514	7,061,026	3,073,551	3,900,966		9,469,568	2,061,295	7,677,916	6,506,836	991,042	3,418,527
$357,420	58	220	159	632	533		164	68	343	423	2,026	4,626
Devon Energy Corp.	451,206,225		1,638,762,889		4,103,610,144	13,974,982	215,749,614	1,082,807,036	1,968,595,422		3,992,059,892	13,466,766,204
DVN	6,266,753		5,444,395		3,864,040	2,329,164	2,538,231	2,455,345	5,640,675		3,548,498	3,913,620
22,330	72		301		1,062	6	85	441	349		1,125	3,441
Southwestern Energy Corp.		2,564,033,622		829,062		4,881,601	15,950,322			10,222,591,341	48,748,035	12,857,033,983
SWN		6,491,224		414,531		813,600	2,658,387			4,865,584	1,874,924	5,069,808
6,690		395		2		6	6			2,101	26	2,536
Pioneer Natural Resources Co.	2,620,313,030		7,296,628,528		739,185,097	3,462,984					327,883,180	10,987,472,819
PXD	4,288,565		3,340,947		4,223,915	1,154,328					1,100,279	3,359,056
29,720	611		2,184		175	3					298	3,271
Encana Corp.	702,045,074		847,485,455		240,775,920	1,323,481,727	1,516,874,262				5,570,119,683	10,200,782,121
ECA	7,020,451		5,296,784		6,507,457	1,721,043	8,819,036				4,748,610	4,230,934
8,070	100		160		37	769	172				1,173	2,411
Apache Corp.	378,710,401		4,438,632,993	1,280,951			101,863	1,211,497,987	108,729,962		2,803,259,632	8,942,213,789
APA	10,519,733		2,834,376	640,476			101,863	1,547,252	4,530,415		2,090,425	2,382,684
18,720	36		1,566	2			1	783	24		1,341	3,753
BHP Billiton Ltd.	5,207,838,243		142,001,785				1,430,812,771	737,650,824		693,704,568	16,980,629	8,228,988,820
BHP	4,629,190		8,875,112				7,083,232	5,464,080		4,784,169	3,396,126	5,054,661
80,190	1,125		16				202	135		145	5	1,628
All Other Operators	40,857,121,422	35,869,648,121	26,197,397,512	24,598,970,191	4,740,004,733	9,369,620,049	5,934,539,303	9,353,815,421	9,754,175,241	669,021	38,139,161,065	204,815,122,079
	5,219,356	6,515,831	2,615,294	2,954,476	2,193,431	2,220,815	4,468,780	2,480,460	4,421,657	133,804	1,476,259	2,876,576
	7,828	5,505	10,017	8,326	2,161	4,219	1,328	3,771	2,206	5	25,835	71,201
Totals	82,069,086,232	45,715,266,643	43,462,283,840	28,278,834,512	17,841,567,907	16,960,787,409	16,660,608,422	15,467,330,702	14,673,407,775	13,852,295,652	63,384,729,101	358,366,198,195
	5,587,873	6,260,650	2,964,281	3,029,334	3,346,131	2,299,456	5,960,862	2,652,149	4,917,362	5,092,756	1,729,933	3,267,827
	14,687	7,302	14,662	9,335	5,332	7,376	2,795	5,832	2,984	2,720	36,640	109,665

Wastewater and Earthquakes a Significant Concern

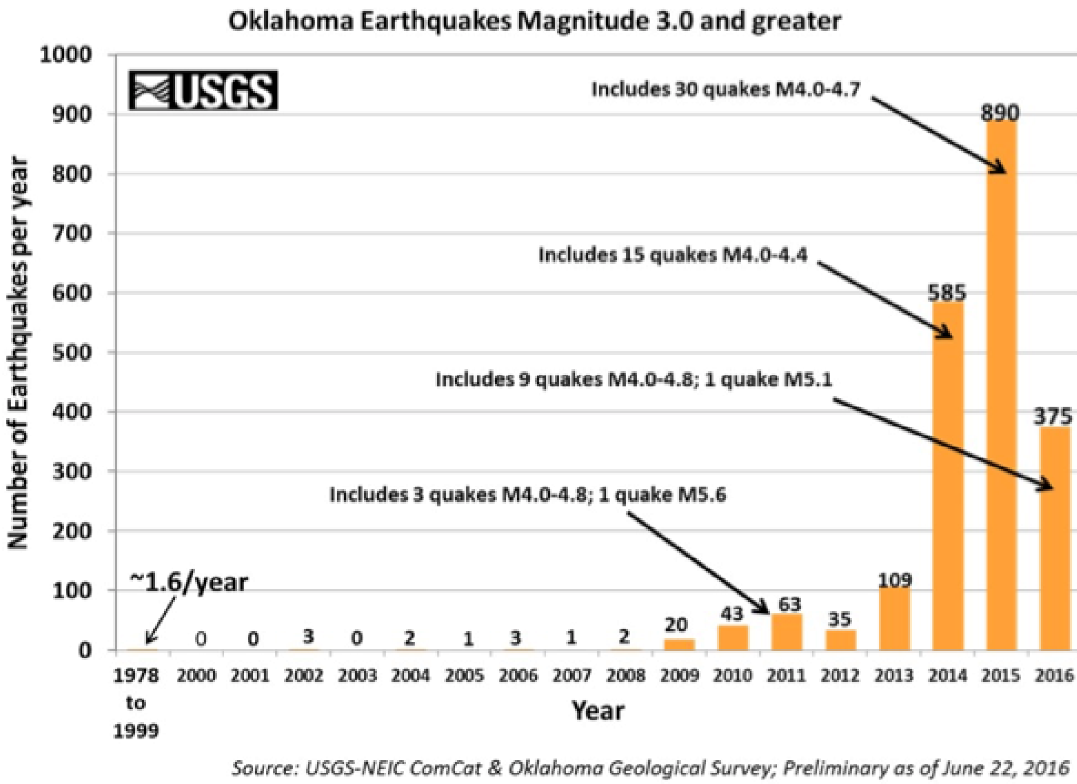
Fracking wastewater is a growing issue. It is often laden with fracking fluid chemicals and additional contaminants of concern like radionuclides. Over time wells produce much more wastewater than oil or gas (often 10 to 1). Water management costs and issues will therefore continue to rise, despite declines in production at many sites.

The volume of wastewater returning to the surface varies widely, depending on geology. In some regions wells return almost nothing, while in others virtually all water is returned.

Wastewater risks are not unique to fracking and shale energy development. Conventional oil and gas wells also produce large volumes, such as in California.

Wastewater returned to the surface is most often disposed of through deep well injection. However these disposal sites – estimated at 680,000 in all, nationally – are not a foolproof solution. [7] Incidents have occurred, such as leakage into aquifers, surface water contamination, and induced earthquakes.

Oklahoma has literally been the epicenter of earthquake activity linked to wastewater disposal, with significant quakes (3+ magnitude) increasing from approximately two per year before 2009 to close to 890 in 2015 (USGS). A similar pattern has been developing in Canada, in particular near Northeastern British Columbia and Northwestern Alberta, where the number of earthquakes has increased from zero per year in 1990, to almost 350 earthquakes in 2015. [8] [9]



Source: "Oklahoma Earthquakes Magnitude 3.0 and Greater." USGS-NEIC ComCat & Oklahoma Geological Survey, June 22, 2016. Accessed September 22, 2016. http://earthquake.usgs.gov/earthquakes/byregion/oklahoma/OKeq-graph-M3-06-22-2016.jpg

Given that many public wastewater treatment facilities are not able or allowed to process fracking wastewater, a major obstacle that industry, local regulators and communities must overcome is how to deal with the risks posed by ever growing volumes of wastewater, especially if deep well injection is no longer viable. In other regions of the world, such as the European Union, deep well injection sites are prohibited. Commercial and onsite recycling and treatment solutions will have to play a bigger role moving forward. And operators may have to walk away from well development in certain regions due to lack of wastewater disposal options.

Recommendations

Given the significant water risks operators are facing in the shale energy sector, investors and lenders need to understand how those water risks could impact their investments. The following recommendations capture crucial steps companies should take to lessen their water impacts and reduce exposure to water risks.

- **Disclose to investors, stakeholders and regulators:** the percentage of current and future expected revenues and operations that are in regions of water risk or wastewater management challenges; how the company is assessing water risks internally and mitigation measures such as recycling and water efficiency programs.

- **Implement operational practices to minimize water use and wastewater risks**; collaborate with industry peers and other industries on local water sourcing challenges; develop local source water protection plans; minimize the use of aquifer exemptions and deep well injection disposal sites due to earthquake risks.
- **Engage with stakeholders**, including: local communities on water needs and waste water plans before starting operations and after they begin; local and regional regulators on water challenges; employees and suppliers to provide incentives for reducing water use.
- **Embed consideration of water risk** across all business units and business planning activities, from the boardroom to the drill site.

For more recommendations to investors, lenders and shale energy companies for mitigating their exposure to water sourcing risks, including improvement of on-the-ground practices, see:

- **Report: Ceres' Hydraulic Fracturing & Water Stress: Water Demand by the Numbers**
- **Brief: Ceres' Investor Engagement Guide on Fracking Water Use and Disposal**

For more recommendations to investors on broader environmental and social issues in shale energy development see:

Extracting the Facts: An Investor Guide to Disclosing Risks from Hydraulic Fracturing Operations

Methodology

This interactive map and accompanying text and figures build upon Ceres' 2014 analysis of water use trends in hydraulic fracturing, "*Hydraulic Fracturing and Water Stress: Water Demand by the Numbers*." It evaluated water use in hydraulic fracturing operations in the 20 largest and most active basins across the continental United States, in addition to the Monterey Basin in California. The research is based on well data available from FracFocus.org, via IHS (formerly PacWest Consulting Partners) and water stress data provided through the World Resources Institute's Aqueduct Water Risk Atlas.

The analysis is based on the water-use data of 109,665 oil and shale gas wells hydraulically fractured between January 1, 2011 and January 31, 2016. All graphs and charts display analysis of the data over that timeline, except when the graph displays information over time, in which case the dates are January 1, 2011 – December 31, 2015. Only wells in the contiguous United States were included in this analysis, and certain offshore wells were excluded based on latitude and longitude parameters or if obvious errors in the data existed.

The data included the following parameters for each well: API number, fracture date, state, county, associated play or basin, latitude and longitude, production type, total vertical depth, water volume used in hydraulic fracturing, operator name and service provider name.

Due to changes in taxonomic classification, the "Permian Basin" referenced in the 2014 report, is divided in this report into the "Central Permian," "Delaware," and "Midland" plays. XTO's wells are labeled as being developed by ExxonMobil given XTO is a subsidiary of the company.

Acknowledgements

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Notes:

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[1] Extrapolating from the EPA's estimates that "70 to 140 billion gallons required for hydraulic fracturing being equivalent to the total amount of water used each year in roughly 40-80 cities with a population of 50,000" in EPA's Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, February 2011.

[2] Source: Andrew Kondash and Avner Vengosh, Water Footprint of Hydraulic Fracturing, Environmental Science and Technology letters, 2015, 2-276-280 http://pubs.acs.org/doi/ipdf/10.1021/acs.estlett.5b00211

[3] Extrapolating from the EPA's estimates that "70 to 140 billion gallons required for hydraulic fracturing being equivalent to the total amount of water used each year in roughly 40-80 cities with a population of 50,000" in EPA's Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, February 2011.

[4] It was not possible to differentiate whether the source of the water was fresh, recycled, saline or wastewater.

[5] Due to changes in taxonomic classification, the "Permian Basin" referenced in the 2014 report, is divided in this report into the "Central Permian," "Delaware," and "Midland" plays.

[6] Tanya J. Gallegos et al, Hydraulic fracturing water use variability in the United States and potential environmental implications, Water Resources Research, AGU Publications, July 24 2015, 10.1002/2015WR017278

[7] Abrahm Lustgarten, "Poisoning the Well: How the Feds Let Industry Pollute the Nation's Underground Water Supply," ProPublica, December 11, 2012.

[8] "Oklahoma Earthquakes Magnitude 3.0 and Greater." USGS-NEIC ComCat & Oklahoma Geological Survey, June 22, 2016. Accessed September 22, 2016. http://earthquake.usgs.gov/earthquakes/byregion/oklahoma/OKeq-graph-M3-06-22-2016.jpg

[9] Andrew Nikiforuk, "Fracking Industry Has Changed Earthquake Patterns in Northeast BC," The Tyee, July 21, 2015, accessed September 21, 2016. http://thetyee.ca/News/2015/07/21/Fracking-Industry-Changed-Earthquake-Patterns/